Unparticle physics in $e^+e^- \longrightarrow PP$ annihilation

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Abstract

In the recent past,unparticle physics effects have been explored in detail in both the fermionic and bosonic sectors. We have used fermionic unparticles to study the cross-section of electron-positron annihilation to light pseudo-scalar meson pairs $e^+e^- \longrightarrow PP$. We show that this cross-section is sensitive to the scaling dimesion $d_U < 1.4$.

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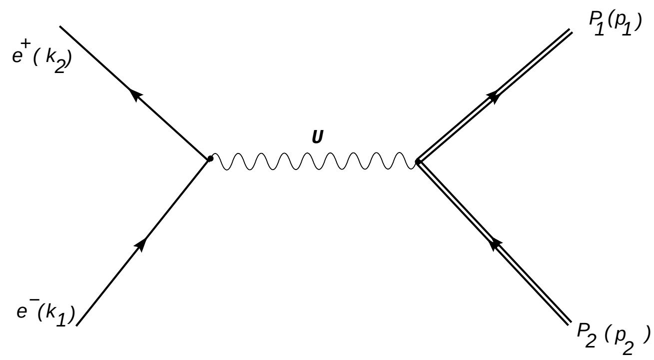

FIG. 1: Feynman diagram for $e^+e^- \longrightarrow P_1P_2$ annihilation

I. INTRODUCTION

Unparticle physics offers promising prospects in the search for new physics beyond the Standard Model (SM) at very high energies above the Tev scale.The broken scale invariance at low energies is restored at very high energies by the non-trivial IR fixed ponit called Banks-Zaks (BZ) fields [1, 2].Below the very high energy scale Λ_U,the renormalizable coupling of the BZ fields introduce the scale invariant "unparticles".These unparticles are massless and have a non -trivial scaling dimension d_U[1].The unparticle scaling dimension d_U is a fractional number rather than an integer.

Recently the effects of unparticle physics on the hadronic sector have been explored [6],[7].In this work , we illustrate the dependence of $e^+e^- \longrightarrow PP$ annihilation cross-section Fig.1 on unparticle physics.

II. FORMALISM

We start with the effective interactions for the unparticle operators coupling to the fermions[4]

$$\frac{c_V^{ff'}}{\Lambda_U^{(d_U-1)}}\bar{f}\gamma_\mu f' O_U^\mu + \frac{c_A^{ff'}}{\Lambda_U^{(d_U-1)}}\bar{f}\gamma_\mu\gamma_5 f' O_U^\mu \tag{1}$$

where O_U^μ is vector unparticle fields with the scaling dimension d_U,$c_V^{ff'}$ and $c_A^{ff'}$ are the dimensionless vector and axial vector coupling constants for fermions.

The $e^+e^- \longrightarrow PP$ annihilation is described in Fig.1.In this process the electron and positron annihilate into an unparticle U which then converts into an outgoing back-to-back

light quark and anti-quark pair which leads to the production of two light pseudo-scalar mesons P_1 and P_2.The propagator of the vector unparticle is given by [2, 6]

$$\begin{aligned} D^{\mu\nu}(P^2) &= \int d^4x e^{iP.x} < 0|T(O_U^\mu(x) O_U^\nu(x))|0 > \\ &= \frac{iA_{d_U}}{2sin(d_U\pi)} \frac{1}{(-P^2 - i\varepsilon)^{(2-d_U)}} (-g^{\mu\nu} + \frac{P^\mu P^\nu}{P^2}) \end{aligned} \tag{2}$$

To obtain Eq.(2),the vector operator O_U^μ is assumed to satisfy the transverse condition $\partial_\mu O_U^\mu = 0$,where

$$A_{d_U} = \frac{16\pi^{5/2}}{(2\pi)^{2d_U}} \frac{\Gamma(d_U + 1/2)}{\Gamma(d_U - 1)\Gamma(2d_U)} \tag{3}$$

The matrix element for the $e^+e^- \longrightarrow PP$ annihilation can be writen as

$$M = \bar{v}_e^s(k_2) \left(\frac{c_V^{ee}}{\Lambda_U^{(d_U-1)}} \gamma_\mu + \frac{c_A^{ee}}{\Lambda_U^{(d_U-1)}} \gamma_\mu\gamma_5 \right) u_e^{s'}(k_1) < P_1(p_1)P_2(p_2)|J_\nu|0 > \tag{4}$$

$$\frac{iA_{d_U}}{2sin(d_U\pi)} \frac{1}{(-P^2 - i\varepsilon)^{(2-d_U)}} (-g^{\mu\nu} + \frac{P^\mu P^\nu}{P^2}) \tag{5}$$

where $P^2 = (k_1 - k_2)^2$ and the current

$$J_\mu = \frac{1}{3} \left(\frac{c_V^{qq'}}{\Lambda_U^{(d_U-1)}} \bar{q}\gamma_\mu q' + \frac{c_A^{qq'}}{\Lambda_U^{(d_U-1)}} \bar{q}\gamma_\mu\gamma_5 q' \right) \tag{6}$$

The factor 1/3 is introduced for normalization purposes of the different colors of quark. The vacuum to two pseudo-scalar amplitude is usullay expressed in terms of a form factor $F^{(q)}$ [8]

$$< P_1(p_1)P_2(p_2)|\bar{q}\gamma_\mu q'|0 > = (p_1 - p_2)_\mu F^{(q)}(q^2) \tag{7}$$

Where $q^2 = (p_1 - p_2)^2$.The axial part of this amplitude is zero. For a massless electron and positron the matix element square is reduced to

$$|M|^2 = \frac{|g_U|^2 |F^{(q)}|^2}{9} c_3^2 [(c_1^2 + c_2^2)(2k_1.qk_2.q - k1.k2q^2)] \tag{8}$$

Where $c_1 = c_V^{ee}$,$c_2 = c_A^{ee}$,$c_3 = c_V^{qq'}$ and

$$g_U = \frac{A_{d_U}}{\Lambda_U^{2(d_U-1)} 2sin(d_U\pi)} \frac{1}{(-P^2 - i\varepsilon)^{(2-d_U)}} \tag{9}$$

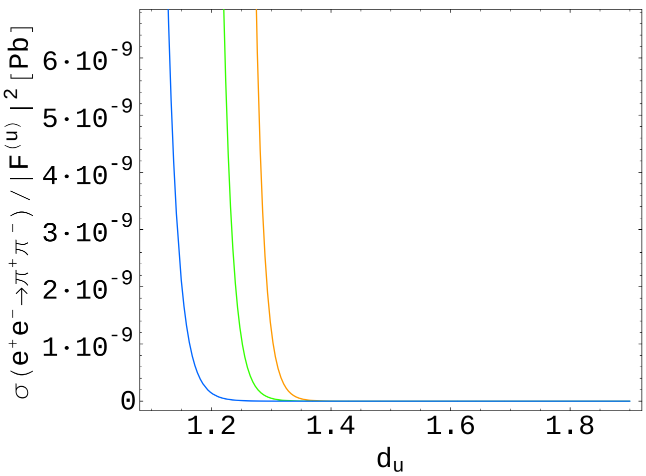

FIG. 2: At $\Lambda_U = 1Tev$,Variation of $\sigma(e^+e^- \longrightarrow \pi^+\pi^-)/(|F^{(u)}(s)|^2)[pb]$ with the scaling dimension d_U for $c_1 = c_2 = c_3 = 1/\sqrt{2}$, $\sqrt{s}$ =5 Gev (red),10 Gev (green) and 25 Gev (blue).

In the centre of mass (CM) frame the momenta of particles are

$$\begin{aligned}
k_1 &= (Ee, 0, 0, Ee) \\
k_2 &= (Ee, 0, 0, -Ee) \\
p_1 &= (Ee, 0, p_{cm}sin\theta, p_{cm}cos\theta) \\
p_2 &= (Ee, 0, -p_{cm}sin\theta, -p_{cm}cos\theta) \\
E_e^2 &= s/4 \\
P^2 &= -s
\end{aligned} \tag{10}$$

where the center of mass enegy $s = (k_1 + k_2)^2$.
Finally the $e^+e^- \longrightarrow PP$ annihilation cross-section σ is obtained in terms of the scaling dimension,coupling constants and the form factor,

$$\sigma(e^+e^- \longrightarrow P_1P_2) = \frac{s}{216\pi}\left(1 - \frac{4m_P^2}{s}\right)^{3/2} c_3^2(c_1^2 + c_2^2)|g_U|^2|F^{(q)}(s)|^2 \tag{11}$$

As an illustration, at $\Lambda_U = 1Tev$ the variation of $e^+e^- \longrightarrow \pi^+\pi^-$ annihilation cross-section as a function of d_U is presented in Fig.2 in unit of $|F^{(u)}(s)|^2[pb]$ for $c_1 = c_2 = c_3 = 1/\sqrt{2}$.We can see from Fig.2, the variation of this annihilation cross-section is sensitive to the scaling dimension $d_U < 1.4$ and rapidly reaches zero above d_U=1.4 . Similar range for the scaling dimension d_U has been obtained from the direct CP asymmetry $A_{CP}(B_d \longrightarrow \pi^+\pi^-)$

[6].

In this work, we have extended the scaling invariance based unparticle physics into the $e^+e^- \longrightarrow PP$ annihilation. Similar analysis can be done for $e^+e^- \longrightarrow VP/VV$ annihilation.

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